CREATIVE COMPOSITES GROUP

5th Percentile Design Strength Value Development for Pultruded Crossarms

In Support of the Creative Composites Group, FRP Utility Crossarm Technical Brochure

WHITE PAPER

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Introduction

Download the CCG FRP Utility Crossarm brochure:

https://www.creativecompositesgroup.com/resources/literature#utilities

In 2007, the National Electric Safety Code (NESC) standards committee adopted composite poles, crossarms and braces into the code. This action was a significant step in mandating that the composite electrical structures manufacturing industry publish their design strength values to a 5% Lower Exclusion Limit (LEL). Utilities that are designing structures with the NESC requires manufactures to publish their design values to the 5th percentile strength. This paper creates transparency for the utility engineer, in that it describes the test methods, test setup, statistical calculations and relevant standards that were used to generate 5th percentile design strength values for the CP2500 crossarm, as published in the Creative Composites Group FRP Utility Crossarm Brochure.

The Creative Composites Group crossarms have all been evaluated per ASTM D8019-15. Standard Test Methods for Determining the Full Section Flexural Modulus and Bending Strength of Fiber Reinforced Polymer Crossarms Assembled with Center Mount Brackets.

Investigation

The following mechanical characteristics were evaluated in order to obtain the 5th percentile strength values for design, standards development and quality control purposes:

- Bending Strength at Failure for Deadend and Tangent Crossarm Configurations
- In-plane Shear Strength at Failure
- Flexural Modulus of Elasticity
- Pin-Bearing Strength at Failure
- Minor Axis Bending Strengths for Deadend Crossarms
- Deadend Bracket Guy Mount Testing

Experiment

Bending Strength, In-plane Shear Strength, Pin-bearing Strength and Flexural Modulus of Elasticity

Figure 1: *Deadend Test Setup*

The bending strength, in-plane shear strength, and flexural modulus of elasticity determined from full section testing of fabricated crossarm specimens, including the mounting brackets and commercially available phase hardware. Lengths, ranging from 5' to 12', were tested in both deadend and tangent configurations. The 3-5/8" x 4-5/8" deadend crossarms were assembled with grade 50 steel braceless deadend brackets, mounted to the crossarm with 3/4" diameter galvanized A325 grade bolts. The phase hardware consisted of 5/8" double-arming (DA) bolts, 3.5" square x 3/8" thick washers, eye nuts and lock washers. Deadend crossarm lengths, ranging from 5' to 12', were tested in a three point bend configuration. The arms were suspended by the 5/8" phase hardware simulating conductor loads while the load was applied through the center mount bracket (see Figure 1) until a failure occurred. Both major and minor axis bending strengths were scrutinized.

Figure 2: *Tangent Test Setup*

Tangent crossarms, ranging from 5' to 12', were tested in the tangent test fixture (see Figure 2) until failure. The tangent crossarms were secured to a steel pipe by means of a grade 50 steel tangent braceless bracket. The steel pipe, representing a pole structure, supported the arm in a tangent configuration while the phase loading was applied into the crossarm through 5/8" DA bolts, a 3.5" x 3/8" steel washer, and eye nuts until a failure occurred.

For both the deadend and tangent tests, the load and deflection measurements were obtained by means of a calibrated load cell, displacement head, and/or a series of string pots. The data was logged into the computer database by means of a data acquisition center at a rate of two data points per second.

Pin Bearing Strength

Pin bearing strength, for both the lengthwise (LW) and crosswise (CW) direction, was determined by subjecting crossarm samples to severe loads, resulting in pin bearing failure. Steel plates were through-bolted with a 5"x 3/4" A325 grade bolt (see Figure 3). The arm was placed directly on the T-slot table of the 250 kN Instron-test machine. A load was induced through the steel plates, into the pin which creating a pin bearing stress on the arm. The load was applied until failure occurred. The corresponding load was correlated to the ultimate pin bearing strength. The ultimate load is defined as the first ply failure load or deviation from the linear load vs deflection curve.

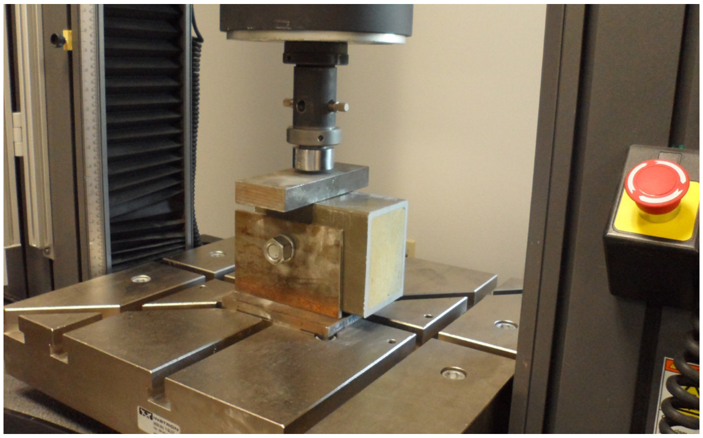


Figure 3: *CW Pin Bearing Setup. The LW pin bearing strength was determined in the same manner. The crossarm was positioned so that a lengthwise pin bearing force was applied into the arm.*

Calculations, Results and Observations

Deadend Crossarm - Shear Strength

A total of 69 deadend crossarms were tested to failure. The failure modes included in-plane shear and bending failures or, more specifically, local compression buckling of the compression flange. The failure modes were consistent with typical failure modes observed in other pultruded product lines. Twenty-six specimens, ranging from 5' to 8', failed due to the in-plane shear capacity of the arm being exceeded. This is typical due to the shear influence associated with shorter spans. Of the 26 shear failure specimens, five specimens were excluded from the statistical analysis as outliers. They were considered outliers because a non-commercial steel deadend mount bracket was used during the test. CCG chose to test all of the arms as manufactured-ready-for-commercial sale to the utility.

The tested crossarms' in-plane shear strength was determined by calculating the in-plane shear stress at failure as:

$$\tau_{max} = \frac{VQ}{It}$$

Where:
τ_{max} = maximum transverse shear stress, psi
I = moment of inertia, in^4
Q = static moment of area, in^3
t = thickness of region or regions under consideration, in.
V = maximum in-plane shear force, lbf.

The resulting average in-plane shear strength for the deadend crossarms was determined to be 5,401 psi with a standard deviation of 256 psi, a coefficient of variation of 6% resulting in a 5% LEL in-plane shear design strength of 4,863 psi.

The shear strength can also be defined as the in-plane shear force at failure. Calculated as the total load at the bracket divided the by the number of phases tested. For example, the average failure load of a 5' CP2500 crossarm was determined to be 20,919 lbf applied to the center mount bracket. The resulting shear force equates to the total load divided by 2 or 10,459 lbf.

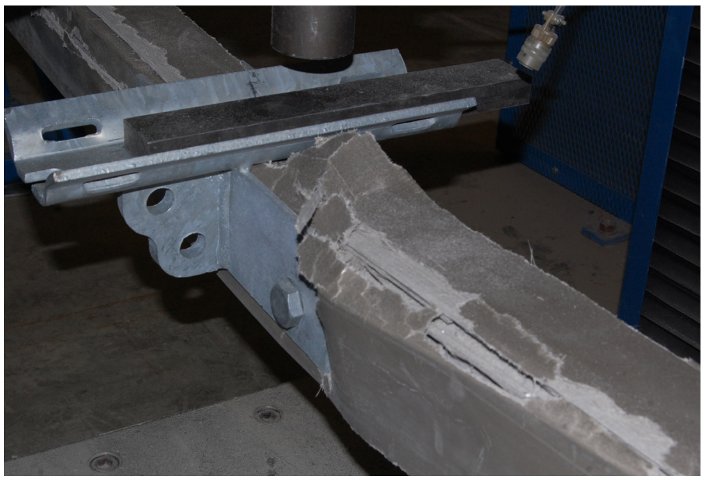
The average shear force at failure was utilized to establish the phase loading capacity for arms with four phases. The sum of the phase loads, on either side of the center mount, must be less than the shear force measured for two phase condition. The assumption was made that the same installation parameters will be used for each of the phases. Therefore, the four phase allowable loading is equal to the total applied average load divided by 4, or 5,230 lbf. The 5% LEL phase load capacities were derived by utilizing the LEL shear force at failure derived from the crossarms that were tested per ASTM D8019-15. Note: The literature values were rounded down to the nearest 100 lbs.

***Figure 4:** Typical In-plane Shear Failure at the Neutral Axis*

Deadend Crossarm - Major Axis Bending Strength

Twenty-three of the 69, major axis tested, deadend crossarms tested failed due to local compression buckling of the compression flange. The 10' and 12' deadend arms failed in this manner due to the heavy influence of bending stresses associated with longer spans. The compression stress at failure was determined by computing the induced moment at failure and dividing by the section modulus of the 3-5/8" x 4-5/8" hollow rectangular crossarm. The analysis considers the arm to be in a four-point bend scenario by distributing the applied load at the centermount to the two bolts mounting the centermount to the crossarm.

Figure 5: Local Compression Buckling Failure

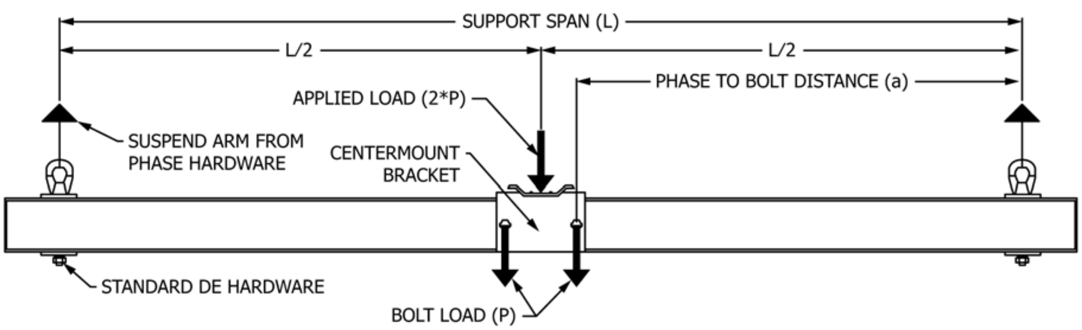


Therefore, the bending stress at failure was calculated by solving for s, where:

$$\sigma_{max} = \frac{Pa}{S}$$

And: σ_{max} = stress due to bending, psi
P = maximum load acting through a single center mount bolt, lbf.
S = section modulus about the neutral axis, in^3
a = distance from phase hardware to the center mount, in

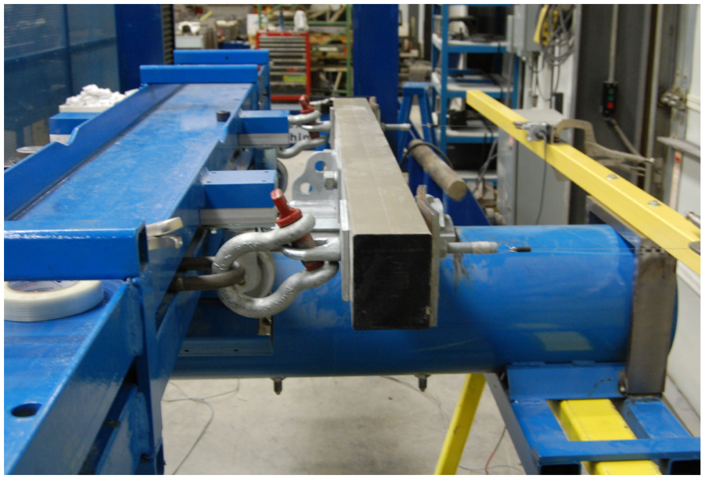
Figure 6: Load Diagram



The resulting average bending strength for the deadend crossarms was determined to be 80,900 psi with a standard deviation of 2,377 psi, a coefficient of variation of 3% resulting in a 5% LEL bending design strength of 76,688 psi.

Deadend Crossarm - Major Axis Bending Strength

Figure 7: *Minor-axis Bending Strength Test Setup*



Both the major axis and minor axis bending strengths have been determined and documented. A typical deadend crossarm exhibits a major and minor axis bending stress due to catenary angles and line tension. Utility design engineers can evaluate their major and minor axis loads against the published design values.

The minor axis bending strength of the deadend crossarm was determined by testing 20 crossarms ranging from 5’ to 12’ in length. The crossarms were loaded in the tangent test fixture with typical deadend hardware in order to impose transverse loads on the crossarm. The typical failure mode was local compression buckling at the arm and deadend bracket interface as depicted in the following photo.

Figure 8: *Minor-axis Bending Failure Mode*

Deadend Crossarm - Major Axis Flexural Modulus

The flexural modulus of elasticity was determined by analyzing the load versus deflection data of spans with span-to-depth ratio greater than 16:1. Specifically, data collected for the 10' and 12' crossarms tested in the major axis deadend configuration was utilized to calculate flexural modulus. The flexural modulus was calculated by analyzing the crossarm in a four point bend configuration. The resultant is based on a minimum of five data points extracted between 30% and 70% of the ultimate load.

The flexural modulus was determined by solving for E where:

$$E = \frac{Pa(3L^2 - 4a^2)}{24\delta I}$$

where:

a = distance from phase hardware to the center mount bolt through the crossarm. in.
E = flexural modulus, psi
I = moment of inertia about the neutral axis of the crossarm, $in.^4$
L = support span, in.
P = load acting through a single center mount bolt, lbf.
δ = deflection relative to the applied load, in.

The average modulus of elasticity was determined to be 6.02E6 psi. The coefficient of variation was 2%. The average modulus of elasticity should be used for predicting the deflection of a pultruded crossarm. Therefore, the flexural modulus is not factored based on a 5% LEL.

Tangent Crossarm - Bending and Shear Strength

Tangent arrangement pultruded crossarms are typically hung with steel braceless mounts. Therefore, a degree of eccentricity exists as the arm is not supported symmetrically about the shear center. One can conclude the importance of testing arms in both deadend and tangent configurations in order to understand the true structural characteristics of the system.

Twenty-four crossarms were tested in tangent configurations, as depicted in Figure 2. The failure modes ranged from in-plane shear to bending or local compression buckling of the compression flange. The in-plane shear strength was determined in the same manner as the deadend arm.

The in-plane shear strength of the tangent arm is less than the deadend arm due to the eccentric loading caused by bracket to arm and arm to pole connection.

The average in-plane shear strength based on the failure modes of the 5', 8' and 10' arms was determined to be 3,254 psi with a standard deviation of 243 psi, a coefficient of variation of 7.8% and a 5% LEL in-plane shear design strength of 2,836 psi.

The resulting average bending strength for 3-5/8" x 4-5/8" tangent crossarms was determined to be 62,408 psi with a standard deviation of 1,094 psi, a coefficient of variation of 2.1% resulting in a 5% LEL bending strength of 60,257 psi.

Pin Bearing Strength

The pin bearing strength, tested as described previously, produced the pin bearing design strength results for both the LW and CW directions. Like wood, composites exhibit strength and stiffness values that are relative to the LW and CW directions.

The results of eleven specimens, tested in CW pin-bearing, produced a mean value of 18,770 psi, a standard deviation of 1,630 psi, a coefficient of variation of 10.2% and a 5% LEL design value of 15,620 psi.

The results of thirteen specimens, tested in LW pin-bearing, produced a mean value of 33,110 psi, a standard deviation of 3,840 psi, a coefficient of variation of 12.6% and a 5% LEL design value of 26,240 psi.

***Figure 9:** Typical CW Pin Bearing Failure*

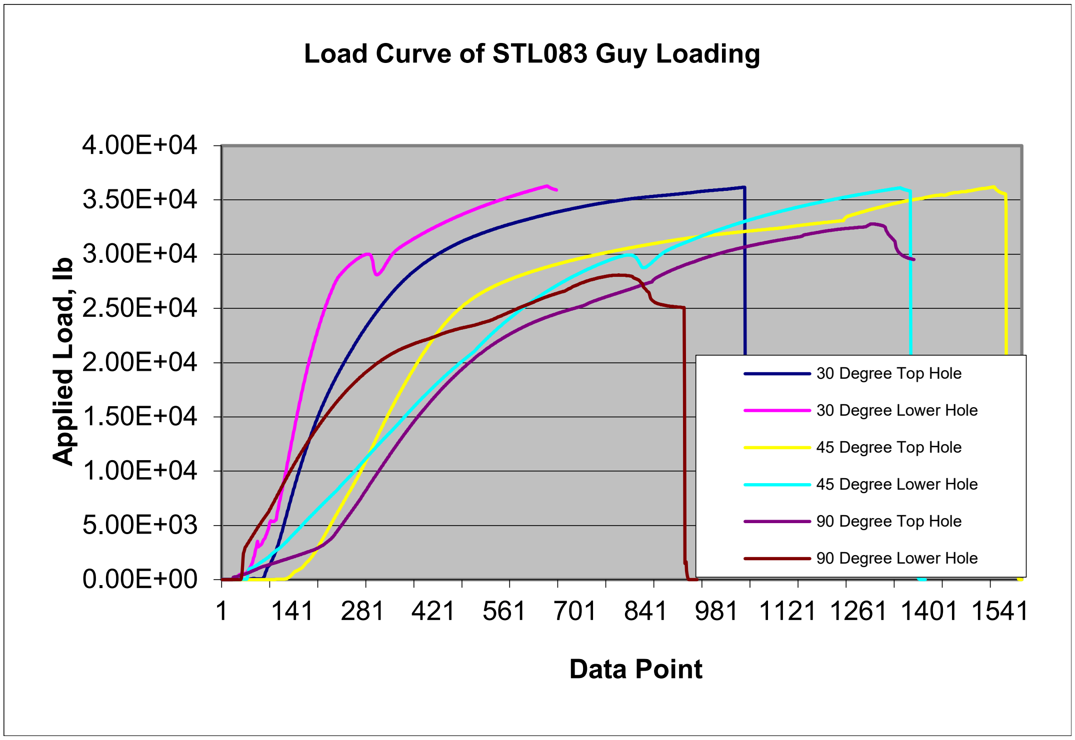
None of the full-section arms failed in pin bearing during the full-section testing. Therefore, lab specimens were utilized to produce the pin bearing design strength values.

Deadend Mount Guy Attachment Capacity

The capacity of the CP2500 deadend bracket guy attachment was evaluated by physically loading the brackets at guy angles including 30°, 45° and 90°. The 90° degree direction is parallel to the phase. Each guy hole was loaded independently.

***Figure 10:** Deadend Guy Bracket Guy Testing*

***Figure 11:** Deadend Guy Bracket Guy Testing Results*



The 30° and 45° tests demonstrated a capacity of over 36,000 lbf. per guy hole before the test was stopped. There was no sign of large scale yielding within the bracket. Slope changes observed in the load curves are the result of yielding of the bolts attaching the bracket to the fixture. The 90° degree test force deformed the bracket yielding the steel at 28,000 lbf.

Phase Capacity

The phase capacities, corresponding to each arm length and type, were derived based on the governing failure stresses. The published phase capacity charts consider the arm length, phase positions and phase quantities for both deadend and tangent crossarms. The 5% LEL and average in-plane shear and bending stresses for each scenario, described in the technical data charts of the CCG FRP Utility Crossarm Technical brochure, dictate the phase capacity. The phase capacity, published for each scenario, represents the behavior of the arm described. In the event the utility utilizes the arm in a different manner, the phase capacity described may not be relevant.

The approach of publishing phase capacities, as well as the mechanical properties, permits CCG's engineering team and the utility engineer to analyze various arm lengths, phase positions and phase quantities that are specific to the application.

Bolt Torque Protection

Over-torque protection is achieved with Creatives patented torque protection system. The system has been tested with torque wrenches and impact wrenches. Creative's guarantees torque protection up to 250 lbf-ft. Testing indicated that torque loads up to 500 lbf.-ft. can be tolerated.

Figure 12: *Torque Test Results Calibrated Torque Wrench*

Load Applied (lbf.-ft.)	Observations
250 - 300	No cracking or visual damage
400 - 450	No cracking or visual damage
450 - 500	No cracking or visual damage
570	Cracking occurred at radius/flat interface on the 3-5/8 inch surface of the TR410 crossarm

Figure 13: *Torque Test with Impact Wrench*

Observations

Failure modes are dictated by the arm length, phase position, phase quantities and hardware details. In some instances, the hardware governs the capacity of the crossarm. The utility is cautioned to validate that the proper hardware is utilized in the field. If the vendor calls out a specific washer size, it is important that the correct washer be utilized. A good example is the failure mode of the washer pulling through the end of the arm. This failure mode is caused by using an improperly sized square washer.

Figure 14: Failure Caused by Improper Washer Size

The vendor is responsible to provide the utility with sound engineering design values. The utility should validate the degree to which the values have been statistically manipulated. If the utility is utilizing the NESC, the values should be published as 5% Lower Exclusion Limit Design Values.

It was observed that the in-plane shear strength of the 3-5/8" x 4-5/8" crossarm varied based on the arm being tested as a tangent or a deadend. The actual in-plane shear strength of the material did not change. The change is due to the center mount and eccentricity that exists with a tangent arm configuration. The near pole web of the crossarm profile is loaded at a higher rate than the far side due to the inherent bracket assembly.

The 5% in-plane shear strength of the tangent arm is approximately 2,836 psi, while the deadend arm exhibited an in-plane shear strength of 4,863 psi. The % in-plane shear strength reduction is 42% for the tangent configuration. One can conclude that it is important to test the tangent arm in a tangent configuration in order to obtain the system behavior and the true design strengths.

As companies, industries, and product lines mature, tribal knowledge is eventually captured and communicated in terms of specifications, codes and standards. The pultruded crossarm industry has matured significantly over the last twenty years. The most significant upswing in crossarm usage has been over the last ten years with the trend line aggressively pointing upward. The upward trend is due to the utilities' desire to increase grid reliability, enhance safety and to reduce labor.

Over the next three years, the composites industry will be introducing more codes and standards for crossarms and poles. The standards will further secure the use of pultruded arms and poles and will permit effective communication between manufactures and end users, resulting in grid and product reliability. You are encouraged to procure the ASTM crossarm test standard by downloading:

ASTM D8019 - 15 Standard Test Methods for Determining the Full Section Flexural Modulus and Bending Strength of Fiber Reinforced Polymer Crossarms Assembled with Center Mount Brackets

Concluding Points

- 5th Percentile design values have been determined and documented, for each crossarm model, in CCG's crossarm brochure which can be accessed by clicking: https://www.creativecompositesgroup.com/resources/literature#utilities
- This white paper provides transparency for utility standards engineers so they can understand how crossarm strength values were derived by CCG.
- It is important that the utility standards engineer verify that the design values are published to a 5% lower exclusion limit.
- It is important to understand that the manufacturer or the engineer of record must be consulted if the crossarms are to be loaded in a fashion not described in the manufacturer's literature.
- CCG provides the necessary information for the engineer of record to determine the crossarm behavior for load scenarios not described in the brochure.
- Torque Testing, utilizing Creative's patented torque protection system, indicated that a torque capacity of 500 lbf-ft can be tolerated, but not recommended.
- Utilities are encouraged to mandate that the FRP crossarm supplier test their arms in accordance with ASTM D8019-15.

ABOUT THE COMPANY

Creative Composites Group is a custom design, engineering and Fiber Reinforced Polymer (FRP) fabrication provider. We offer comprehensive engineering, design and consultation for unique fabrication projects. Our manufacturing capabilities include the broadest range of engineered FRP solutions to build your ideal projects. That's possible only with our proven engineering processes, end-to-end collaboration, service and support resources. Since FRP composites last longer than conventional materials they often have a lower lifetime cost when you consider longer service life and low to no maintenance costs.

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